1993
Executive Research Project
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Standard Target Materials For Autonomous Precision Strike Weapons

Steven P. Wallach

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94-07670

48 pgs

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94 3 8 11

DTIC QUALITY INSPECTED 5

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION	1b. RESTRICTIVE MARKINGS
Unclassified	

2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT
N/A	Distribution Statement A: Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
N/A	

4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
NDU-ICAF-93-δ77	Same

6a. NAME OF PERFORMING ORGANIZATION	6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
Industrial College of the Armed Forces	ICAF-FAP	National Defense University

6c. ADDRESS (City, State, and ZIP Code)	7b. ADDRESS (City, State, and ZIP Code)
Fort Lesley J. McNair Washington, D.C. 20319-6000	Fort Lesley J. McNair Washington, D.C. 20319-6000

8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS			
	PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification) Standard Target Materials For Autonomous Precision Strike Weapons

12. PERSONAL AUTHOR(S) Steven P. Wallach

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Research	FROM Aug 92 TO Apr 93	April 1993	53

16. SUPPLEMENTARY NOTATION

17.	COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

SEE ATTACHED

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☒ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
Judy Clark	(202) 475-1889	ICAF-FAP

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted. SECURITY CLASSIFICATION OF THIS PAGE
All other editions are obsolete.

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Accession For		
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DTIC TAB	☐	
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Justification		
By		
Distribution/		
Availability Codes		
Dist	Avail and/or Special	
A-1		

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Over the years, civilized nations have shown the moral desire to minimize collateral damage and casualties to noncombatants when bombing enemy targets through the development and use of precision munitions. The next generation of precision strike weapons are now being developed to fly autonomously from launch to target. Several guidance technologies are being explored, with advances in high speed digital computers now allowing terminal sensors to acquire the target, correlate the sensed image with a stored "template" of the target area, and guide the weapon to the target with precise accuracy. To better support these emerging systems, a target material standard and operations concept for mission planning autonomous terminal sensor weapons will be suggested.

STANDARD TARGET MATERIALS

FOR AUTONOMOUS

PRECISION STRIKE WEAPONS

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STANDARD TARGET MATERIALS
FOR AUTONOMOUS
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One element of war is the bombing of enemy targets. In
doing so, civilized nations have the moral desire to minimize
collateral damage and casualties to noncombatants. These are
not new ideals, as evidenced by a 55 year old Army Command and
Staff School manual on strategy which said:

> An air raid which involves in its accomplishment
> the wholesale destruction of non-combatants cannot
> be justified or condoned. Any nation employing
> such methods will be condemned by the civilized
> world. Air raiding among civilized nations will
> have to be confined to military or semi-military
> objectives.[1]

The bombing of Hiroshima and Nagasaki in World War II,
although contradictory to this premise, strengthened these
feelings. In Desert Storm, the world watched in awe while U.S.
smart munitions struck targets with pinpoint accuracy.

The next generation of precision strike weapons are now
being developed and will begin deployment in the mid 1990s.
These new systems will fly autonomously for significant
distances from launch to target, providing greater standoff for
the launch platform, thereby lessening risk. While several
guidance technologies are being explored, the more
sophisticated systems are expected to use a terminal sensor to
acquire the target, correlate the sensor's returned image with

that of a stored reference scene of the target area, and guide the weapon to its target with precise accuracy.

Currently, the various system development activities, and their contractors, are identifying the qualitative requirements for terminal reference scenes or templates. To better support these emerging systems, a standard digital target material must be defined which will support the generation of target templates for multiple weapons.

This paper will use the Joint Cruise Missiles Project as a case study to examine the use of standard target materials in Navy and Air Force cruise missiles. Emerging autonomous weapons and mission planning systems will be explored and a target material standard and operations concept for autonomous weapons mission planning will be suggested. Finally, the benefits of standard digital target materials will be provided.

THE JOINT CRUISE MISSILES PROJECT: A CASE STUDY

To begin, we will examine the Joint Cruise Missiles Project and the development of Terrain Contour Matching (TERCOM) data as standard target material to support navigation updates for U.S. cruise missiles.

Cruise Missile Development

Following the end of World War II, both the Air Force and Navy began to pursue the development of cruise missiles. By the early 1970s, guidance and jet engine technology had

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matured to the point that both Services were beginning to conceptualize cruise missiles into their strategic force structures. Supported by then Secretary of Defense Melvin Laird, Congressional funding was obtained for cruise missile development through an FY72 Supplemental Appropriation. Up to this time, the Services had proceeded independently. In 1973, the first steps toward a joint program emerged as OSD directed the Air Force to support Navy work on TERCOM guidance, and in April 1974, McDonnell Douglas Astronautics Company (MDAC) and E-Systems were selected to compete for the development of the guidance and navigation sets for the Navy's Sea Launched Cruise Missile (SLCM).[2]

Following a Defense Systems Acquisition Review Council (DSARC) meeting in February 1975, the Navy was directed to select a single navigation/guidance contractor for both SLCM and the Air Force's Air Launched Cruise Missile (ALCM). In March 1975, the ALCM program office provided the Navy with performance requirements for ALCM. Through the summer of 1975, a competitive TERCOM flyoff was held and in October 1975, MDAC was selected as the guidance system contractor for ALCM and SLCM.[3]

The DSARC II decision memorandum of January 14, 1977, created the Joint Cruise Missiles Project Office (JCMPO), with the Navy named the lead service.[4] JCMPO was directed to manage the ongoing ALCM and SLCM development efforts, and authorized to develop the Ground Launched Cruise Missile (GLCM). The decision memorandum further directed JCMPO to:

> Maximize subsystem/component commonality...to
> utilize fully joint test and evaluation...and
> derive maximum benefit from joint service
> management.[5]

A flyoff competition for ALCM production, between Boeing (AGM-86B) and General Dynamics-Convair Division (GDC), teamed with McDonnell Douglas, was held between July 1979 and February 1980. Boeing was selected as the ALCM contractor, and the GDC team was selected to produce SLCM and GLCM.[6]

In November 1978, the JCMPO forwarded specifications and requirements to the Defense Mapping Agency (DMA) for a standard TERCOM product to support ALCM, SLCM, and GLCM. An extensive TERCOM test program took place from 1981 to 1984 to quantify TERCOM performance prediction for differing terrain types and environmental conditions. Later in the 80s, the Advanced Cruise Missile (ACM) was also developed using the standard TERCOM product for navigation aiding. While GLCM was eliminated by the Intermediate-range Nuclear Forces (INF) Treaty of 1988, other cruise missiles are operational and flight testing continues to this day.[7]

Operational Concept of Cruise Missiles

After receiving launch orders at the platform, the fire control system inserts the current geoposition into the missiles inertial navigation system (INS) and mission data (including route, missile commands, and TERCOM mapsets) are digitally loaded into the missile's computer. Following

launch, the missile is autonomously guided to the target by its INS. To reduce INS errors, the missile flies a predetermined route, periodically updating its position through TERCOM navigation updates. Figure 1 depicts a typical cruise missile mission.

TERCOM data, produced by DMA, is extracted as a digital terrain matrix from stereo imagery. The matrix data goes through a validation process where the uniqueness and the accuracy of the digital terrain data are evaluated to predict performance (i.e. probability of update), and a suitable TERCOM mapset is output.[8]

Typically, three sizes of TERCOM mapsets (Landfall, Enroute, and Terminal) are used to reduce the missile's navigation error and increase accuracy at the target. The Landfall, largest in both matrix size and elevation interval spacing, supports initial INS updates after long stand-off flights from the launch platform. The Enroute is of moderate size and resolution to support INS update during enroute navigation. Finally, the Terminal is the smallest TERCOM product, which acts to funnel the missile to effectively attack the target. Although TERCOM is labeled a target material, it was developed for strategic (i.e., nuclear) cruise missiles and will not support terminal delivery accuracies required for conventional weapons.[9]
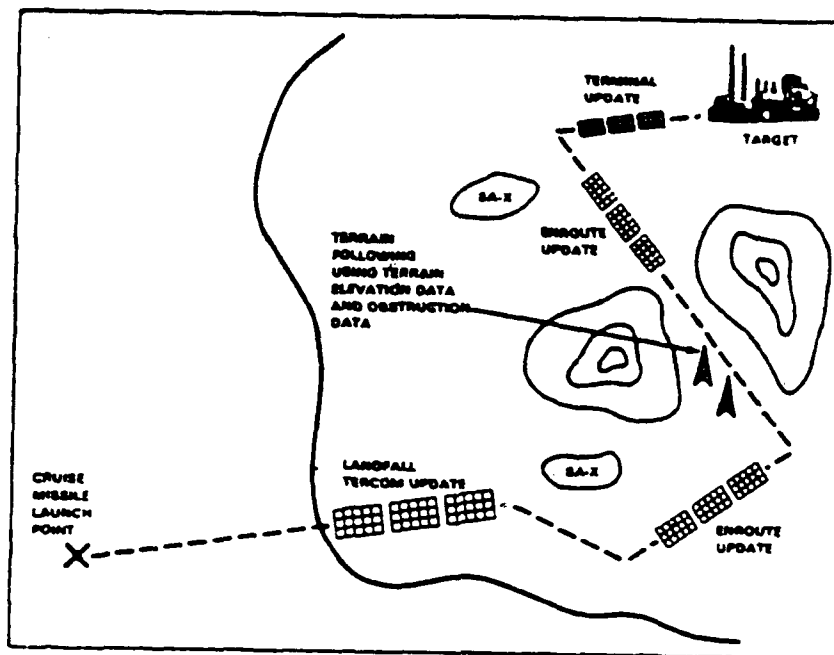
Figure 1 - Typical Cruise Missile Mission
(Source: "DMA Support to Cruise Missiles")

At the mission planning center, the missile's route is planned from the launch area to the target, the associated TERCOM maps are retrieved, overall mission performance is predicted, and the mission data (including the TERCOM maps) are loaded to a data transfer device (DTD). Finally, the mission data (including TERCOM) are loaded from the DTD into the missile.

As the missile flies, it ʌnses its height above the terrain with its radar altimeter while its barometric altimeter senses the missile's height above mean sea level. By differencing the two altimeter readings, the elevation of the
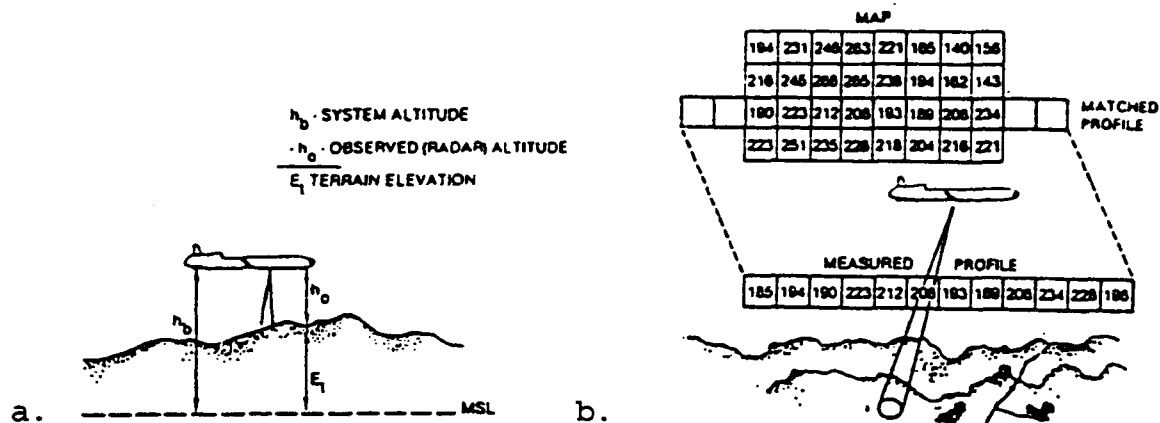
Figure 2 - (a) TERCOM Measurement, (b) TERCOM Match
(Source: "DMA Support to Cruise Missiles")

terrain is determined. After the mean elevation is removed to eliminate biases, the sensed terrain profile is correlated with the stored TERCOM mapset. If a match is found, the relative location of the missile within the mapset is determined. Because the TERCOM mapset is accurately positioned to the World Geodetic System 1984 (WGS-84) the missile's INS can be updated relative to the target.[10] See Figure 2.

Together, the TERCOM (Landfall/Enroute/Terminal) updates act as a funnel, reducing the missile's INS error to achieve accurate autonomous guidance from launch to target.

Benefits of Standard TERCOM Product

The primary benefits of a standard TERCOM product are cost savings and improved interoperability. From FY78 through the end of FY92, DMA produced 6,425 TERCOM mapsets at a total cost of approximately $37.56M (FY92) dollars. If system-unique

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TERCOM products (for each cruise missile) had been developed, the cost would have been several times higher.[11]

Interoperability was also improved because each system benefitted from the others TERCOM requirements/production. For example, when GLCM was eliminated in the 1988 INF Treaty, the TERCOM mapsets produced for GLCM were not thrown away, but saved for use by other cruise missile systems.[12]

In the end, the TERCOM product has supported multiple cruise missile systems to deter the former Soviet nuclear threat for well over a decade. TERCOM also supported conventionally-armed Tomahawk cruise missiles in Desert Storm and will continue to do so in future conflicts.

EMERGING AUTONOMOUS WEAPONS

In July 1992, the Director of Defense Research and Engineering identified seven thrust areas for the Defense Science and Technology (S&T) program which represent the "most pressing military and operational requirements."[13] Although funding is currently in question, the "Precision Strike" thrust describes its objective as:

> The desire for reduced casualties, economy of force, and fewer weapons platforms demands that we locate high-value, time sensitive fixed and mobile targets and destroy them with a high degree of confidence within tactically useful timelines.[14]

Guidance Technology

To meet this objective, the Services and Defense Agencies are pursuing a number of initiatives focused on supporting two primary concepts for terminal guidance. These are: 1) Global Positioning System (GPS)-aided inertial systems, and 2) terminal sensor systems. Additionally, multiple guidance methods could be used concurrently in the same system.

GPS-aided inertial guidance integrates a GPS receiver with the weapon's INS. Through signals received from a constellation of GPS satellites, heading and velocity errors are reduced by updating the weapon's position with accuracy at the target projected at 45 feet circular error probable (CEP).[15]

From a mission routing standpoint, the GPS/INS guided weapon is relatively simple. Accurate coordinates will be obtained from GPS and loaded into the launch platform and weapon. The GPS/INS guided weapon will fly to the predetermined target location. It also may be possible to electronically transmit new target coordinates to the launch platform or the weapon while in enroute to the target area, thereby improving operational flexibility.[16]

GPS-aided INS guidance has two primary error sources which affect overall system accuracy: the uncertainty of the weapon's position in flight, and target location error.[17] Development efforts are investigating Differential GPS as a means to reduce the uncertainty of the weapon's location.

Although there are various employment options for Differential GPS, typically a receiver is placed at a known (surveyed) location which serves as a "base station," and relative differences between the base receiver and the GPS receiver on the weapon are computed. Using Differential GPS, weapon location can be determined to approximately 1 meter versus 16 meters using a single receiver on the weapon. Although differential GPS will improve accuracy, there are operational employment drawbacks.[18]

Additionally, there are a number of development efforts aimed at providing more accurate and timely target coordinates. These include DMA's development of the Digital Point Positioning Data Base (DPPDB), the Rapid Positioning Capability (RPC) development effort, and others.[19]

The viability of GPS/INS terminal guidance and the size of the target set assigned to weapons using these methods will depend on the success of the ongoing accuracy improvement initiatives. As GPS/INS guidance delivery accuracy improves, there will be less need for more complex terminal sensor guided weapons. Although requirements for terminal sensor guidance may be reduced, they will not be eliminated. The accuracy of terminal sensor weapons will continue to be required to effectively attack hardened, high-value targets.

The Services are investigating a number of candidate terminal sensors, including: imaging infrared (IIR), laser
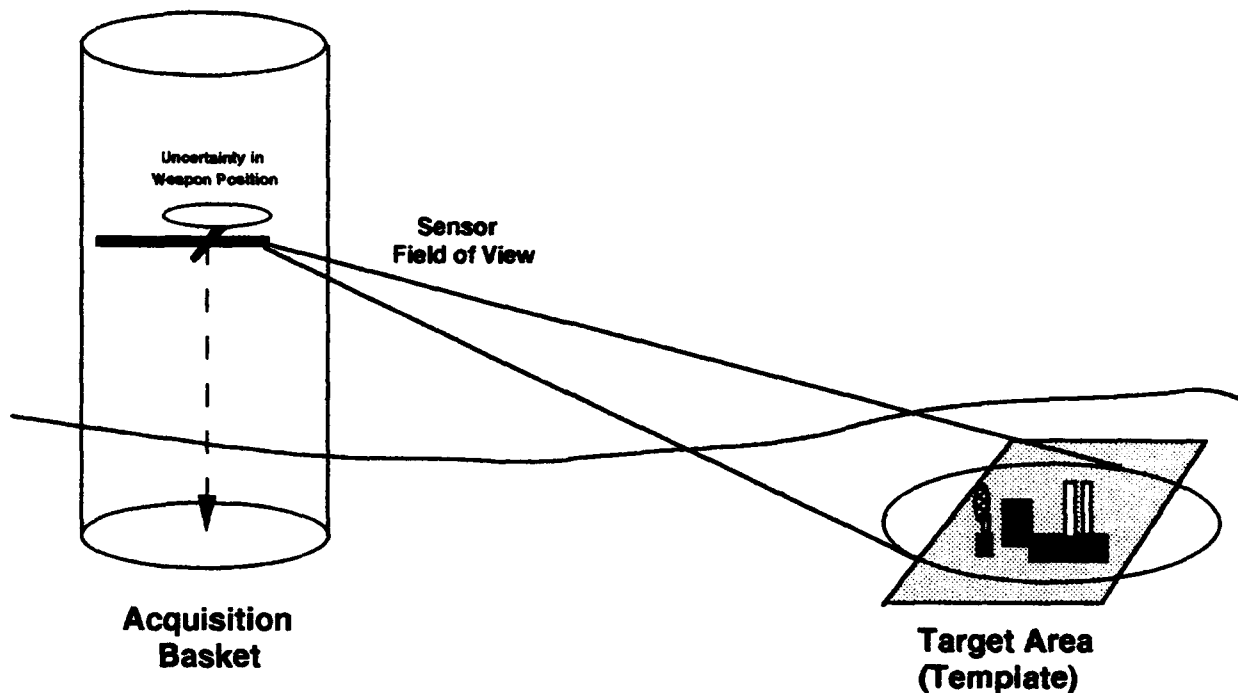
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Figure 3 - Terminal Sensor Weapon Concept

radar (LADAR), synthetic aperture radar (SAR), and millimeter wave (MMW) real beam radar, and electro-optical (EO). Multimode and fuzed sensor systems (e.g., MMW+IIR) are are also being considered. The concept is for the weapon to fly to an acquisition basket a few kilometers from the target. At this point, the weapon will activate its terminal sensor, pointed at the target area, and attempt to correlate the sensed image with a target template that was produced during mission planning. While correlating on a direct (or offset) aim point, the weapon is projected to strike the target with an accuracy of 10 feet CEP.[20] Figure 3 illustrates the terminal sensor guidance concept.

The accuracy of a terminal sensor-guided weapon is dependent on several factors, including:

- the weapon's positional accuracy (absolute) in the acquisition basket,

- the quality/accuracy (absolute and relative) of the preplanned template,

- the sensor's resolution and its ability to correlate on the template (in a variety of natural and induced environments), and

- the weapon's ability to steer out errors during terminal approach.[21]

Terminal Sensor Weapons

The development of terminal sensor technology has continued since the 1970s. These efforts started with terminal sensor technology research and development and evolved through several false starts on actual weapons programs. Some of the programs which led to the current development efforts include:

- Autonomous Terminal Homing (ATH),

- Cruise Missile Advanced Guidance (CMAG),

- Modular Standoff Weapon (MSOW),

- Long-Range Conventional Standoff Weapon (LRCSW), and

- Advanced Guidance Evaluation Program (AGEP).

There has been renewed interest in autonomous weapons since Desert Storm where the benefits of precision strike standoff weapons were demonstrated by laser guided bombs, Tomahawk, ALCM-C, and others.[22] With standoff weapons, manned aircraft and aircrews faced less risk because of increased standoff ranges, while minimizing collateral damage. Since Desert Storm, several new autonomous weapons programs have emerged, including the:

- Joint Direct Attack Munition (JDAM).

- Joint Standoff Weapon (JSOW),

- Tomahawk Baseline Improvement Program (TBIP),

- Tri-Service Standoff Attack Missile (TSSAM), and the

- Sensor Fuzed Weapon.

After years of research and development, the Defense Acquisition Board met in June 1992 and approved JSOW for engineering and manufacturing development (Milestone 2) and JDAM to begin concept exploration (Milestone 0).[23] JSOW, previously known as the Navy's Advanced Interdiction Weapon System (AIWS), dispenses submunitions for use against soft targets. Although unpowered, the range of JSOW is expected to be up to 40 miles. Initially, JSOW is planning on an integrated GPS/INS guidance set, with an initial operational capability (IOC) scheduled for 1997. As a follow-on, JSOW will be investigating other munitions and terminal sensors for employment against hard targets.[24]

JDAM combines the Air Force's Adverse Weather Precision
Guided Munitions program with the Navy's Advanced Bomb Family.
JDAM will be developed in three phases. Phase 1 will add a
GPS/INS guidance kit and some form of weapon control to MK 84
and I-2000 bombs, making the bombs autonomous, all-weather
capable and improve delivery accuracies. JDAM-Phase 2 will
focus on a new fuze and warhead, and Phase 3 will investigate
terminal sensor guidance.[25]

As stated above, JSOW and JDAM are both evolving toward
terminal sensor guidance. Additionally, the Tomahawk Baseline
Improvement Program (TBIP) is also investigating terminal
sensors. With these weapons, and others, considering terminal
sensor guidance, the issue of a standard target materials must
be addressed.[26]

MISSION PLANNING

Before addressing standard target materials for terminal
sensor weapons and their integration into the mission planning
process, we will first look at mission planning in general.

Evolution of Mission Planning

The process of aircraft mission planning remained
relatively uncharged into the 1980s. In general, the aircrews
planned missions by plotting the aircraft's route and waypoints
on paper aeronautical charts, manually computing fuel
consumption and other aircraft performance parameters.

Additionally, static radar predictions were manually sketched for enroute waypoints and aimpoints.

The aeronautical charts, with route information, were cut into strips and carried into the cockpit to be used during the flight. Mission planning was a tedious and time consuming process which resulted in a significant workload and dependence on the aircrew to fly the aircraft and monitor the status of the mission.

Although digital aircraft flight control systems (e.g., F-111) had emerged, it was the advent of the cruise missile that forced the development of automated mission planning systems. Because cruise missiles have no pilot to make in-flight corrections and monitor mission status, a capability had to be developed to load the mission data directly into the missile's navigation and guidance computer; hence, the birth of today's automated mission planning systems. To support this process, requirements for digital mapping, terrain, imagery, threat, and weather data emerged. In the mid-1980s, aircraft mission planning began taking place on digital graphics workstations with the mission data loaded into the aircraft's flight computer via a data transfer device (e.g.,cartridges, optical discs, etc.).

As digital data processing and media technology evolved, mission planning capabilities increased. In the late-1980s, the services began loading digital map and terrain data into

the aircraft for moving map display and terrain following/ avoidance systems. The improvements made in mission planning and aircraft avionics over the last decade have resulted in reduced pilot workload, allowing more time to focus on the mission objective. Some of the functions performed by today's mission planning systems are listed below.

- Route planning with fuel consumption,

- Detailed threat analysis with autorouting,

- Edit flight parameters,

- Weapons loadout calculations,

- Aircraft refueling,

- Terrain radar masking,

- Terrain Perspective scenes,

- Mission rehearsal (with broad area imagery)

- Radar prediction displays,

- Radar preset, waypoint, and offset aimpoint data,

- Prints strip charts,

- Prepares combat mission folder,

- Loads data transfer devices, etc.[27]

Standardization Efforts

Advances in computer technology and increased defense spending throughout the 1980s provided a basis for the rapid development of automated mission planning systems. However, these same factors resulted in a proliferation of unique mission planning systems within the Services, with virtually

every new aircraft having its own mission planning system,
(e.g., AV-8B, B-2, F-117, etc.).

In 1986, the Secretary of the Navy (Lehman) mandated a
standard mission planning system be developed for the Navy
and Marine Corps. Although the conversion process was slow,
the Tactical Aircraft Mission Planning System (TAMPS) has
become the Navy/Marine Corps standard.[28]

The situation within the Air Force was more complex. Its
aircraft fell into four basic functional groups that were
separated by command.

Function	Command
Strategic	Strategic Air Command (now Strategic and Air Combat Commands)
Tactical	Tactical Air Command (now Air Combat Command)
Transport	Military Airlift Command (now Air Mobility Command)
Special Operations	Special Operations Command

The drive towards a standard Air Force mission planning
system had to not only gain the confidence of the individual
aircraft program offices, but overcome command rivalries as
well. Initially, each command had its own mission planning
systems and architecture which were not interoperable. In
1989, the Air Force defined requirements for the development
of a standard unit-level mission planning system. As a
result, the Air Force Mission Support System (AFMSS), which

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                    STANDARD                          MISSION PLANNING
                    DATABASES                             EXECUTIVE
                      - Maps                            - Route Planning
                      - Intel        INTERFACE          - Threat Analysis
                      - Weather       CONTROL           - Combat Mission
      CORE            etc.                                Folder, etc.
      - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      MODULES

        F-15      F/A-18      B-2      JDAM      JSOW      . . .
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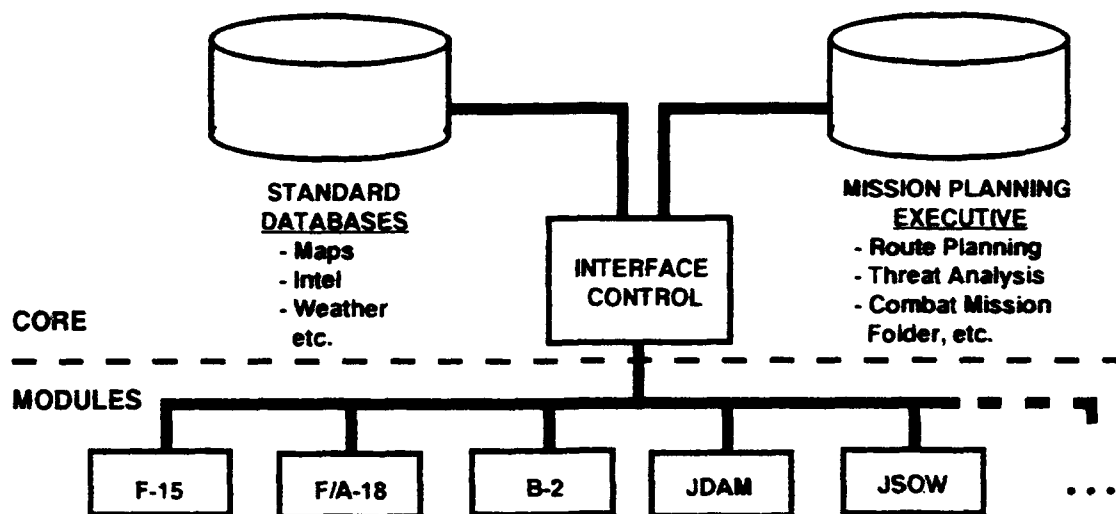
Figure 4 - Mission Planning Open Architecture
(Source: AFMSS and TAMPS briefing slides)

will support mission planning for all Air Force aircraft, was
developed.[29] In late 1992, the AFMSS contract was awarded to
Lockheed-Sanders, with initial delivery planned for 1993.[30]

Along with standardizing within their own Services, the
Air Force and Navy/Marine Corps have been coordinating their
efforts to improve interoperability between the Services. As
examples, the Interservice Mission Planning Working Group
(IMPWG) and the Automated Mission Planning Interoperability
Working Group (AMPSIWG) have focused attention on mission
planning standardization. In particular, these working
groups are pursuing standards for mission planning hardware
and software; mapping, imagery, intelligence, and weather
databases; and data transport devices.[31]

Over the last few years, there has been a move towards open
architecture systems relying on industry standards (e.g., Unix,

Posix, Ada, X-Windows, etc.), which will allow systems to operate on various hardware suites. Additionally, the services have adopted similar modular system designs for AFMSS and TAMPS. As shown in Figure 4, this type of design provides for the use of standard "core" databases and applications software, and with a growth capability for new aircraft and weapons-specific modules.[32]

MISSION PLANNING FOR AUTONOMOUS WEAPONS

Aircraft attack (or strike) mission planning can be divided into three primary phases:

- Ingress: from takeoff to weapons release,
- Weapons delivery: weapons release to target, and
- Egress: return to base.

As described above, ingress and egress mission planning capabilities (for the aircraft itself) have developed rapidly over the past decade.

However, mission planning for delivery of autonomous precision strike weapons is relatively immature. In particular, mission planning for forward look'ng terminal sensor-guided weapons needs additional development before these types of weapons can be employed operationally.

Mission planning for terminal sensor weapons can be divided into two phases: enroute and terminal. The enroute

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phase is from aircraft release until the weapon enters the target's acquisition basket, where the weapon activates its terminal sensor to acquire the target for terminal guidance.

For enroute guidance, most terminal sensor weapons will use GPS to update their inertial systems. Because of this, enroute mission planning for terminal sensor weapons is relatively simple. The center coordinates of the acquisition basket are entered in the mission data and the weapon flies to that location in space.[33]

Mission planning for the terminal phase is more complex, requiring the construction of a terminal reference scene or template which will be stored in the weapon's guidance computer. As the weapon enters the acquisition basket, its sensor is activated, and the sensed image of the target area is correlated with the template stored in memory, with navigation updates occuring repeatedly from the acquisition basket to the target.[34] It is the automated production of target templates for terminal guidance which requires development.

Current Trends

As mentioned previously, a number of advanced weapons programs are pursuing terminal sensor guidance, each looking at various sensor types, (e.g. IIR, LADAR, SAR, MMW).[35] Multiple contractors are supporting these efforts, each with their own unique, and often proprietary, methods for building the target template.

Most efforts are focused on using a modified or enhanced version the Basic Target Graphic (BTG) which is managed by the Defense Intelligence Agency (DIA) and produced by the Joint Intelligence Centers (JICs). The BTG, which replaced the Automated Tactical Target Graphic (ATTG), was developed as a target material for "man-in-the-loop" weapons. The BTG consists of annotated paper imagery prints (at various scales), and includes textual attributes which describe items of interests in the target complex, including:

- Length, height, width, and orientation of limited buildings and other features;
- Surface materials (e.g., asphalt, grass, steel),
- Classification (e.g. hanger, POL tank); and
- Geodetic coordinates (latitude, longitude, and elevation) for the center of the complex.[36]

The coordinates on ATTGs and some BTGs are a concern. The location of the coordinate is not always marked on the image prints; nor are the source, accuracy, or datum provided for the coordinates. In reality the coordinates serve only as a general location for the target complex.[37]

Recently, multiple control points have been annotated on the BTG imagery, and the accuracy of the points is generally improved. These coordinates are now provided by DMA or derived from a Point Positioning Data Base (PPDB). Additionally,

"prototype" hardcopy imagery supplements are being developed for various terminal sensors.[38]

Although the enhanced BTG is currently supporting developmental test programs, it is not the optimal target material for the long-term. First, the BTG is a hardcopy product, and mission planning is a digital process. The time required by manually entering information from the BTG will not support high-tempo operations and may lead to unnecessary collateral damage from input errors.

Additionally, the imagery provided in the BTG is monoscopic (single image) and does not allow the measurement of terrain elevations. Although shadow measurement techniques on monoscopic imagery allow the accurate measurement of features, (e.g., buildings, towers, etc.), there is no way to measure the relief displacement, or relative (point-to-point) elevation difference, between two features. This uncertainty in the vertical axis may be tolerable if the weapon is in a direct attack mode, that is, correlating on the actual impact point. However, vertical uncertainty will create significant problems when using offset aim points, particularly in moderate to high relief or when using shallow angles of attack.[39]

Defining a Digital Target Material (DTM) Standard

The answer is to produce a higher fidelity digital version of the BTG which will support template production for multiple weapons/sensors. We will call this the Digital Target Material

(DTM). The DTM must be positioned accurately in an absolute sense on the earth's surface and the positioning of features within the DTM must be extremely accurate in a relative (point-to-point) sense. Finally, the DTM must reside in a standard digital format which can be easily accessed and processed by the mission planning system to build the target template.[40]

During the Advanced Guidance Evaluation Program (AGEP), the Aeronautical Systems Center (ASC) consolidated a set of qualitative requirements for a standard target material to support template generation for multiple sensors. Contractors for several advanced guidance programs provided input, including:.

Sensor   Program

IIR   Autonomous Guidance for Conventional Weapons (AGCW)

LADAR   Advanced Technology Ladar System (ATLAS)

SAR   Advanced Synthetic Aperture Radar Guidance (ASRG)[41]

In April 1992, ASC briefed the results of the AGEP study, defining the characteristics required for a standard target material and identified preliminary requirements for the following:

- Absolute and relative accuracy of control points to position the DTM,

- Size or area of coverage of the DTM,

- Relative (point-to-point) accuracy for feature measurements and displacement between features,

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- Feature orientation accuracy,

- Minimum size of features to be measured,

- Vertical obstructions to be measured,

- Surface materials (e.g. concrete, grass, dirt), and

- Obliquity and resolution of accompanying imagery.[42]

In concluding, ASC emphasized the need for further study to validate these requirements and reiterated the need for accurate digital target materials, saying, "Autonomous precision munitions require precision target materials."[43]

Using the AGEP specification as a baseline requirement for DTMs, we will suggest standards for the digital format, attribute, and imagery standards for DTMs.

Vector Product Format (VPF), MIL-STD-600006 is recommended as the standard digital format for DTMs. VPF, sometimes referred to internationally as the Vector Relational Format (VRF), was developed by DMA with the United Kingdom, Canada, and Australia as an international standard for digital geographic information.[44]

Along with the data structure defined in VPF, the Feature Attribute Coding Catalog (FACC) is recommended as the standard for coding and attributing DTM features. FACC and VRF (VPF) are included in the Digital Geographic Information Exchange Standard (DIGEST) which is currently under review by the Military Agency for Standardization for approval as NATO Standard Agreement (STANAG) 7074.[45] Additionally, DMA products (geographic

information) are being distributed in VPF and FACC standard
formats. Because of this, the applications software needed to
read and display (VPF/FACC) DTM data will exist on the mission
planning system, resulting in shorter timelines and reduced
costs for DTM software development and maintenance. Adoption of
VPF and FACC will also promote interoperability both across
Service lines and with our Allies.

Some mission planners have expressed the desire to drape
imagery over the DTM to display a perspective view of the target
area. Digital imagery, included with the DTM (VPF/FACC) data,
should be provided in the National Imagery Transmission Format
(NITF) standard, as defined by the Defense Intelligence Agency
(DIA). As with VPF/FACC, the use NITF will promote
interoperability.

Although the basic characteristics for a standard digital
target material have begun to emerge, less thought has been
given to the integration of digital target materials and
template generation into the overall mission planning process.

An Operations Concept

At this time, much attention is focused on how to acquire
the imagery to support the generation of the terminal reference
scene. The Services are looking at all potential imagery
sources including: satellites, reconnaissance aircraft, and
unmanned aerial vehicles. In addition, there are several

digital imagery workstation development efforts underway which may eventually support DTM production.[46]

As part of the Theater Mission Planning Upgrade (TMPCU) program, the Navy is providing the Cruise Missile Support Activities at the Atlantic and Pacific Commands with the Digital Imagery Workstation Suite (DIWS). DIWS has the capability to input both digital imagery and digitized hardcopy imagery for Tomahawk mission planning.[47] The Air Force is also studying digital imagery workstations in a program called Talon Scene.[48] Current technology is capable of performing the digital imagery processing necessary to support terminal sensor weapons. With technology continuing to advance and prices decreasing, the primary issue to be resolved is that of an operations concept.

A candidate operations concept for mission planning autonomous (terminal sensor-guided) weapons is illustrated in Figure 5. This concept focuses on a fixed, high value target set, where a standard DTM will be transmitted to the mission planner who will generate the mission specific target template.

This process will occur in the Joint Intelligence Center (JIC) and/or a forward deployed intelligence center during lengthier conflicts. By having DTM production in-theater, reconnaissance assets (including aircraft, unmanned aerial vehicles, etc.) can be better utilized and the operational commander will have direct control.
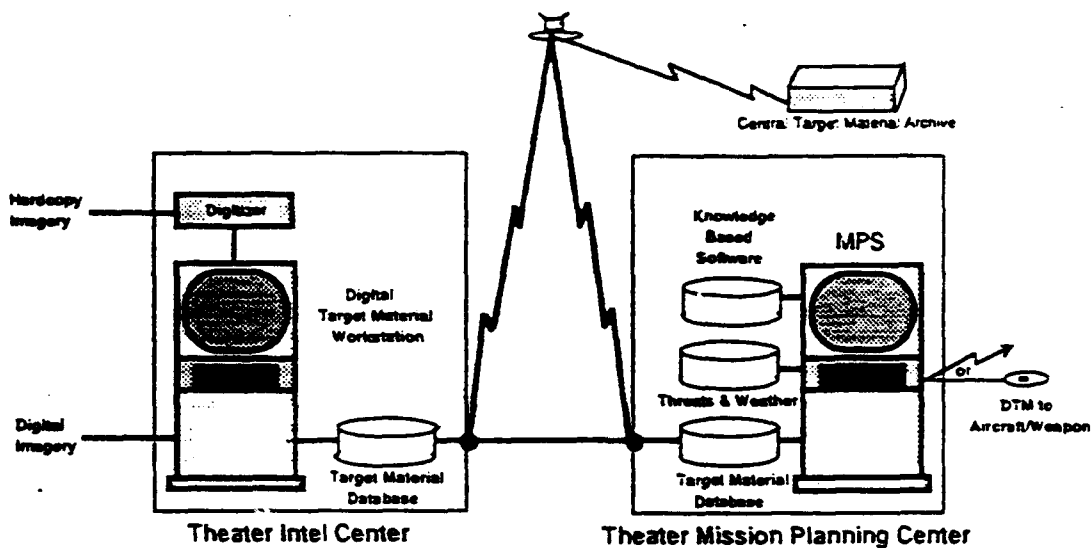
Figure 5 - Mission Planning Architecture for
Autonomous Precision Strike Weapons

Additionally, a means to evaluate the currency of DTMs must be
planned for. In general, as the data content of DTMs increase,
so does the need for maintenance. Use of noncurrent
(inaccurate) DTMs could lead to the weapon not being able to
correlate on the target area. The result is a missed target,
increased likelihood of collateral damage, and increased risks
to our forces. Using the DTM's imagery, a comparison can be
made with current (monoscopic) reconnaissance imagery using
change detection algorithms.

Using a digital target material workstation, an imagery
analyst will extract 3-D feature data in VPF/FACC standard

format to generate a geometric shell of the target area.
Target analysis and weaponeering will be performed to
determine critical target nodes, associated aim points, and
select proper munitions. This information will also be
included as attributes of the DTM. The DTM will be loaded to
the Command or Theater DTM database and transmitted via
satellite communications to a central archive database. This
central database will consolidate all DTMs, facilitate DTM
sharing between Commands, and act as a back-up.

As force-level planning takes place and air tasking
orders are issued, the DTMs for the assigned targets will be
transmitted to the unit-level mission planning operations
center. At the unit-level, the ingress route for the aircraft
will be planned to the point of weapon release, as is done
today. The enroute portion (from weapon release to the
acquisition basket) of weapon's flight is then planned. The
complexity of enroute planning for the weapon will vary
depending on the length and profile of the flight.[49]

The terminal phase of mission planning for autonomous
(terminal sensor-guided) weapons is highly complex. Today,
the planner is expected to make critical judgements about what
features are important to produce a target template for a
particular sensor. To accomplish this the planner must also
consider the weapon's attack profile and expected weather
conditions. In short, there is considerable room for
variation in template content between mission planners for a

given target. These differences in target template content will lead to uncertainty in predicting weapon' performance.

Today's computer technology will allow the production of more consistent target templates through the use of standard DTMs. A proposed concept for terminal area planning will access the DTM for the target, and based on the weapon's flying height, attack azimuth, and distance to the target the DTM will be translated (rotated and scaled). A mission-specific target template will then be automatically generated based on sensor requirements. DTM translation and sensor-specific template generation will be performed by knowledge based software on the mission planning workstation, providing a more consistent target template whose performance can be more reliably predicted.[50]

Finally, the egress portion of the aircraft's flight will be planned. The entire set of mission data will be digitally transmitted (or transferred manually via a data transfer device) to the aircraft and downloaded into the weapon.

Performance Prediction

Performance prediction is the process during mission planning that quantifies the probability for mission success, based on:

- Threat information,

- Aircraft/weapon performance parameters,

- Target variance (complexity, season, time-of-day), and

- Mapping, weather and target material accuracy, etc.

31

Performance prediction is needed to ensure mission success, while minimizing collateral damage; and because of the high cost of terminal sensor weapons. Performance prediction can be broken into phases which address the following four questions:

1) What is the probability that the aircraft will arrive at the weapons release point and launch the weapon?

2) What is the probability that the weapon will fly into its acquisition basket?

3) What is the probability that the weapon's sensor will correlate on the target template?

4) How accurately will the weapon hit the target?

With answers to these questions, the proper number of weapons can be assigned to a target to ensure mission success, while minimizing costs. Existing aircraft and cruise missile algorithms, provide a basis for performance prediction in Phases 1 and 2 . However, performance prediction for Phases 3 and 4 need further development.

At this point, the size and absolute positional accuracy requirements of the weapon's acquisition basket must be considered. The weapon's positional uncertainty in the acquisition basket must be small enough to ensure that the target area is in the sensor's field of view, when activated. Therefore, the field of view and range of the sensor will

directly affect acquisition basket size and accuracy requirements.[51]

In Phase 3, the weapon's ability to correlate the sensed target image with its stored template must be predicted. The relative accuracy of the DTM (and subsequent target template) is critical to sensor correlation. Depending on the sensor type, weather may also have a significant affect the sensor's range and ability correlate.[52]

After the weapon has flown into the acquisition basket, turned on its sensor, and correlated on the target template, the weapon's accuracy at the desired impact point must be computed. Performance prediction in Phase 4 is where the relative (point-to-point) accuracy of the original DTM is most important. In particular, when using an offset aimpoint, relative accuracy (both horizontal and vertical) becomes critical. Inaccuracy in the DTM directly contribute to the weapon's error budget. Therefore it is important to understand the accuracy of the DTM and target template.[53]

The development of reliable performance prediction is an evolutionary process. Existing aircraft and cruise missile performance prediction algorithms, along with data from the weapon's test programs, provide an initial capability. However, the performance prediction algorithms must be updated and tuned as follow-on test data becomes available.

Benefits of Standard Target Materials

Standard DTMs will provide many benefits.

First, by defining a standard DTM specification to support multiple weapons/sensors, the time and cost of system development will be reduced by eliminating redundant, unique, and often times proprietary, software.

Second, by using standard DTMs, instead of time intensive, error prone manual methods, mission planning timelines will be shortened, providing a means to better sustain high tempo operations.

Third, automated target templates produced from DTMs will be more consistent and better quality, leading to more accurate performance prediction for the weapon.

Fourth, with a standard DTM supporting all users, multiple taskings for target imagery will be reduced, freeing up reconnaissance assets to support other requirements.

The end result is improved interoperability and more effective, cost efficient support to the operational commander.

CONCLUSION

Over the next decade, several autonomous (terminal sensor) weapons are likely to be fielded. Standard digital target materials are needed to meet the needs of these emerging systems

and to provide the operational commander with the most effective system possible.

This paper is not intended to provide the final solution, but to stimulate thought about the mission planning process for autonomous weapons. A follow-on working group should be established to flesh out the requirements and specifications for a standard DTM and the operations concept and architecture for autonomous weapons mission planning. The result will be improved interoperability and supportability for future terminal sensor weapons.

ENDNOTES

1   Summers, Harry, "Clash of Bombing Visions." Washington Post G3.

2   Conrow, E.H., Smith, G.K., and Barbour, A.A., The Joint Cruise Missiles Project: An Acquisition History. pp. 4-11 and Newbauer, John, "U.S. Cruise Missile Development." Astronautics & Aeronautics pp. 24-35.

3   Ibid.

4   Ibid.

5   Ibid.

6   Ibid.

7   Phonecons with DMA cruise missile requirements staff.

8   Defense Mapping Agency, DMA TR 8040.1: Mapping Data to Support Cruise Missiles, pp. 3-11 - 3-17, Newbauer, John, "U.S. Cruise Missile Development." Astronautics & Aeronautics, pp. 25 and 32, and Wallach, Steven P., "DMA Support to Cruise Missiles." Proceedings of the Cruise Missiles Technology Symposium 1991., pp. 253-254, Golden, Joe P., Terrain Contour Matching (TERCOM): a Cruise Missile Guidance Aid.

9   Ibid. TERCOM is also used for used for enroute guidance for the conventionally-armed Tomahawk , which then uses an electro-optical sensor (DSMAC) for terminal guidance.

10 Ibid.

11 Phonecon with DMA TERCOM program manager. TERCOM program figures are through FY92, with 939 work years expended (@40K per work year) for a total of $37.56M to produce 6425 TERCOM mapsets

12 Phonecon with former DMA.cruise missile requirements manager.

13 Defense Research and Engineering, Director of, Defense Science and Technology Strategy, ES-3, Holzer, Robert and Munrow, Neil, "DoD Prods Precision Strike Effort," pp. 3 and 28, ànd Munrow, Neil, "DoD Sets Dates for Precision Strike Selections," p. 10.

14 Ibid.

[15] Air Force, Department of, *The Bomber Roadmap*.p. 6, Space
      Navigation Systems, NAVSTAR Global Positioning System Joint
      Program Office, *GPS NAVSTAR User's Overview*., pp. 2-9 and
      Franklin, Mary and Pagnucco, Steve, "Integrated Global
      Positioning System/Inertial Navigation System for Cruise
      Missile Applications,".pp. 65-75. The stated accuracy
      objective of 45', while possible, is dependent on the
      quality of the target coordinates and the method of GPS
      implementation (e.g., Differential GPS).

[16] Defense Mapping Agency, *DMA TR 8350.2: Department of Defense
      World Geodetic System 1984*, 1-1 - 2-3. For GPS/INS systems we
      talk of "absolute" WGS-84 coordinates to tie the weapon and
      target to a specific location on the earth's surface. When
      targeting terminal sensor weapons, "absolute" accuracy is
      less important and "relative" (point-to-point) accuracy
      within the terminal reference scene or template becomes
      critical. Additionally, depending upon the weapon;'s
      flying height and angle of attack other data (e.g. terrain,
      vertical obstructions, etc.) may be important to minimize
      clobber.

[17] While there are additional errors (e.g. vehicle steering),
      weapon location and target location are the two major error
      contributors.

[18] Space Navigation Systems, NAVSTAR Global Positioning System
      Joint Program Office, *GPS NAVSTAR User's Overview*., pp. 2-9.
      Accuracies provided for GPS are 50% spherical error
      probable. While Differential GPS (DGPS) provides improved
      accuracy, several issues provide challenges. DGPS requires
      a surveyed position for a base station, and both the ground
      station and the weapon must receive signals from the same 4
      GPS satellites for 3-D coordinates. DGPS accuracy degrades
      as distance (base-to-weapon) increases, and there are other
      hardware constraints (e.g., multiple antennae, etc.).

[19] Examples of programs to improve targeting include Artemis
      and Warbreaker, and DMA and others are looking at improved
      techniques. The Operational Concept Demonstration, at
      Eglin AFB will provide data on expected GPS/INS guidance
      performance.

[20] Air Force, Department of, *The Bomber Roadmap*.p. 6, Goebel,
      R.H. and Heumphreus, P.R., " The Impact of Terminal
      Guidance Sensors on Cruise Missile Mission Planning,"
      pp. 217-228, Henderson, Robert L., de Sa, E., and Simpson,
      R.K., "Cruise Missile Terminal Seeker Implementation," pp.
      153-165, and Walsh, Edward J., "Next Generation Cruise
      Missile Development Begins," pp. 27-30. The distance of
      the acquisition basket from the target can be affected by
      the range and field of view of the sensor, the weather, the

the positional accuracy of the weapon and/or the size and positional accuracy of the target template.

21   Ibid. Ref. #18 above. Relative accuracy becomes even more critical if an offset aim point is used versus direct attack.

22   "Air Force Launched 35 ALCMS on First Night of Gulf War." Defense Daily p. 88. Tomahawk was previously referred to as SLCM.

23   Air Force, Department of, The Bomber Roadmap.pp.1-18, "Pentagon to Approve JSOW Development, Initial Work on Direct Attack Munition," p. 28 and Holzer, Robert and Opall, Barbara, "Pentagon Will Fund and Manage Effort to Install Seekers on Bombs," p. 19

24   Ibid.

25   Ibid.

26   Holzer, Robert, "U.S. Navy Envisions Tomahawk Upgrades Beyond New Block III." Defense News p. 36. Conventionally-armed Tomahawk now uses an elctro-optical sensor (DSMAC) for near-terminal guidance.

27   Navy, Department of, (DRAFT) Operational Requirements Document for the Tactical Aircraft Mission Planning System (TAMPS), Air Force, Department of, Program Management Directive for Air Force Mission Planning Systems, and numerous AFMSS and TAMPS briefings.

28   Navy, Department of, (DRAFT) Operational Requirements Document for the Tactical Aircraft Mission Planning System (TAMPS) and TAMPS briefings.

29   Air Force, Department of, Program Management Directive for Air Force Mission Planning Systems, and AFMSS briefings.

30   Hughes, David, "USAF Picks Lockheed Unit for Mission Planning System." Aviation Week p. 53.

31   AFMSS and TAMPS briefings. Standardization is a major effort in the mission planning arena. Efforts are being coordinated with DMA and DIA for mapping and imagery standards, along with those the Common Operating Environment (COE) for hardware/software.

32   Hughes, David, "USAF Picks Lockheed Unit for Mission Planning System." Aviation Week p. 53 and AFMSS and TAMPS briefings.

33 Henderson, Robert L., de Sa, E., and Simpson, R.K., "Cruise Missile Terminal Seeker Implementation." and Goebel, R.H. and Heumphreus, P.R., " The Impact of Terminal Guidance Sensors on Cruise Missile Mission Planning." Proceedings of the Cruise Missiles Technology Symposium 1991 pp. 153-166 and 217-228.

34 Ibid.

35 Ibid., Holzer, Robert and Opall, Barbara, "Pentagon Will Fund and Manage Effort to Install Seekers on Bombs." Defense News p. 19, and "Pentagon to Approve JSOW Development, Initial Work on Direct Attack Munition." Aviation Week p. 28.

36 AGEP briefing to USAF Intelligence Support Plan working group, April 1992 and follow-on discussions. Additionally, any given BTG may (or may not) provide all the information needed to develop a template for a terminal sensor weapon.

37 Ibid. Coordinates which are not precisely marked, without an accuracy statement (including confidence level), or without the datum (e.g. WGS-84) identified are of little use for an autonomous weapon. You are dealing with an unknown; the error could range from a few feet to several miles and the user has no idea which.

38 Both the DPPDB and RPC will be tied to WGS-84 and provided with complete accuracy statement. They will support the production of DTM as an actual source material or by providing a means to control other recce imagery.

39 The task of providing source imagery is much simpler if the requirement is monoscopic. However, there is general agreement that for indirect attacks with offset aimpoints stereo imagery is required to minimize relative (point-to-point) vertical errors. Every meter of uncertainty due to relief displacement results in error at the target, unless this weapon attacks the target at a perfect 90 degree dive.

40 Ibid. The DTM will be used to generate mission/sensor-specific target templates for fixed, high-value targets.

41 AGEP briefing to USAF Intelligence Support Plan working group, April 1992 and follow-on discussions.

42 Ibid.

43 Ibid. The results of the AGEP study have been developed through an iterative queries with sensor contractors. Although best estimates have been developed for a standard

DTM requirement (e.g. size, accuracy, orientation, etc.), additional development and testing is needed for verification.

44 Defense Mapping Agency, MIL-STD-600006: Vector Product Format. pp. 1 and 16-17.

45 Ibid. and Digital Geographic Information Working Group, Digital Geographic Information Exchange Standard (DIGEST), Ed 1.1. Part 4.

46 Defense Research and Engineering, Director of, Defense Science and Technology Strategy. pp. II-16-28, Holzer, Robert and Munrow, Neil, "DoD Prods Precision Strike Effort." Defense News pp. 3 and 28, Holzer, Robert, "Navy to Test UAV in Targeting Role." Defense News pp. 2 and 29.

47 Conversation with Cruise Missile Project (PMA-281) staff.

48 Air Force TENCAP briefing to USAF Intelligence Support Plan working group, April 1992.

49 Enroute planning for short, high flights will be relatively simple. Longer and lower flights require more complex mission planning, with digital terrain and vertical obstruction data becoming more important to terrain radar mask threats and avoid clobbering a hill or vertical obstruction.

50 The complexity of developing knowledge based software to automatically build a target template is recognized. However, if rules are established to manually guide the mission planner in template production, the same rules can guide an automated process. The key is consistency to allow accurate performance prediction for the weapon. With costs estimated from $100K to ~$2M per weapon, performance must be well understood.

51 Absolute accuracy refers to the precise location on the earth's surface, typically referenced to WGS-84 with latitude, longitude, and elevation.

52 Relative (point-to-point) accuracy refers to the accuracy of one point to another (deltas) based on a distance and heading. Rain, heavy fog, dust, and other increment weather can affect some sensor (e.g. IIR) range.

53 Ibid. Additionally, the navigation (or weapon steering) error must be factored in with the relative accuracy of the target template. The weapon knows where it wants to go, continues to steer out error, but never quite hits exactly where it plans.

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APPENDIX - ACRONYM LIST

ACM - Advanced Cruise Missile

AFMSS - Air Force Mission Support System

AGEP - Advanced Guidance Evaluation Program

AIWS - Advanced Interdiction Weapon System

ALCM - Air Launched Cruise Missile

AMPSIWG - Automated Mission Planning Interoperability Working
          Group

ASC - Aeronautical Systems Center

ATH - Autonomous Terminal Homing

BTG - Basic Target Graphic

CMAG - Cruise Missile Advanced Guidance

DARPA - Defense Advanced Research Projects Agency

DIA - Defense Intelligence Agency

DIGEST - Digital Geographic Information Exchange Standard

DMA - Defense Mapping Agency

DPPDB - Digital Point Positioning Data Base

DIWS - Digital Imagery Workstation Suite

DTD - Data Transfer Device

DTM - Digital Target Material

EO - Electro-optical

FACC - Feature Attribute Coding Catalog

GLCM - Ground Launched Cruise Missile

GPS - Global Positioning System

IIR - Imaging Infrared

IMPWG - Interservice Mission Planning Working Group

INF - Intermediate Nuclear Forces

INS - Inertial Navigation System

JCMPO - Joint Cruise Missiles Project Office

JDAM - Joint Direct Attack Munition

JIC - Joint Intelligence Center

JSOW - Joint Standoff Weapon

LADAR - Laser Radar

LANTCOM - Atlantic Command

LRCSW - Long-Range Standoff Weapon

MMW - Millimeter Wave Radar

MSOW - Modular Standoff Weapon

MSS II - Mission Support System

NITF - National Imagery Transmission Format

PACOM - Pacific Command

RPC - Rapid Positioning Capability

SAR - Synthetic Aperture Radar

SLCM - Sea Launched Cruise Missile, also known as Tomahawk

STANAG - Standard Agreement

TAMPS - Tactical Aircraft Mission Planning System

TBIP - Tomahawk Baseline Improvement Program

TSSAM - Tri-Service Standoff Attack Missile

TERCOM - Terrain Contour Matching

VPF - Vector Product Format

VRF - Vector Relational Format

WGS-84 - World Geodetic System 1984